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PROTEIN AND ENERGY INTERRELATIONSHIPS IN
FATTENING RATIONS FOR HOLSTEIN BULLS AND STEERS

by



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A THESIS

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Abstract

Holstein bulls and steers were fed rations containing 8.95, 12.99 and 17.02 percent crude protein. The levels were achieved by substituting soybean meal for barley in all-concentrate rations. Each ration was fed at a low, medium or high energy level. The different energy levels were obtained by adjusting the feed intake based on animal metabolic weight. The low, medium and high protein diets supplied 8.26, 11.99 and 15.71 grams of crude protein per unit metabolic weight per day, respectively, while the low, medium and high energy levels provided 318, 358 and 398 kcal gross energy per unit metabolic weight per day, respectively. The average initial weight of the animals was 170 kg and the average slaughter weight was 292 kg.

Average daily gains of the animals fed the low, medium and high protein rations were 0.87, 1.18 and 1.26 kg per day, respectively. Average daily gains of the animals fed the low, medium and high energy diets were 0.87, 1.15 and 1.32 kg per day, respectively. At the low protein level, high energy intake did not improve gains over the medium level of energy. At the low energy level, high protein intake did not improve gains over the medium level of protein. Bulls had a higher daily gain than steers.

Animals fed the low energy diets used 13 percent more gross energy per kg gain than animals fed the medium and high energy diets. Animals fed the low protein diets used 25 more percent gross energy per kg gain than animals fed the medium and high protein rations.

The apparent digestibility of dry matter and gross energy were not affected by changes in the levels of dietary protein or energy intake in this experiment. The apparent digestibility of crude protein was in-

creased when the protein level of the diet was raised.

The average apparent nitrogen retention of animals fed low, medium and high protein rations were 30, 53 and 95 grams per day, respectively. Animals fed the low, medium and high energy diets had average apparent nitrogen retentions of 41, 63 and 76 grams per day, respectively. Increasing the energy level increased the response to additional dietary protein. Also, increasing the dietary protein consumption increased the response to additional energy intake. The percent of apparent digestible nitrogen which was retained by the animals was increased by increasing the energy intake in animals fed the low and medium protein diets. The percent of apparent digestible nitrogen retained did not increase with increasing energy intake in animals fed the high protein ration.

Indices of separable carcass fat and lean showed that increasing the energy intake increased the percent of separable carcass fat. This trend was more pronounced in animals fed the low protein diet than in animals receiving the medium and high protein rations. The percent of separable carcass lean increased with increasing dietary protein intake. This trend was more evident in animals fed medium and high energy diets than in those receiving low energy diets. Carcasses from bulls contained less separable fat and more separable lean than carcasses from steers.

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Introduction

Protein and energy are the most costly components to supply in the ruminant diet. Although it has long been recognized that the level of energy in the diet affects the protein requirements for poultry and swine, there has been relatively little work done on the effect of energy level on the protein requirements of ruminants.

Within limits poultry and swine tend to consume feed of different nutritive values in amounts which maintain a constant intake of metabolizable energy. Thus, by relating the level of dietary nutrients to the metabolizable energy of the feed rather than to feed weight, the daily intake of nutrients will remain constant over a wide range of feeds with different nutritive values. A further benefit is seen in that the dietary nutrients will be locked in balance with metabolizable energy. Ruminants, however, do not consume feed to maintain a constant metabolizable energy intake. With ruminant rations, the level of dietary nutrients are adjusted to the feed weight, keeping in mind the estimated or recommended feeding level. The level of dietary nutrients are not locked to the metabolizable energy intake with the result that the ratios of dietary nutrients to metabolizable energy may vary widely over a range of feeds with different nutritive values. The level of production which might be expected from these various balances of nutrients with respect to energy intake are not well defined.

The action of the rumen microflora on the ruminant's supply of dietary nutrients complicates the study of relative protein and energy needs. Estimates of the relative levels of protein and energy in the carcasses of ruminant animals or the relative level of protein and energy required for the metabolic activities of the ruminant do not

necessarily provide good estimates of the ratio of protein to energy required in the ruminant diet. The relative requirements of protein and energy for the host animal may not match the rumen microflora's relative needs of these nutrients which will enable it, in turn, to supply the host with optimum levels.

A further complication arises from the many possibilities as to what may constitute optimum. Certainly, the relative costs of inputs and how they affect the value and quantity of the product must be considered in establishing optimum levels. The same daily weight gains may be attained by feeding several different combinations of dietary protein and energy. The composition of these gains, however, may vary widely with respect to carcass fat and lean.

This experiment was conducted to study the effects of feeding diets containing different protein-to-energy ratios at different levels of energy intake. The effects of these diets and energy levels on daily gain, efficiency of feed utilization, nutrient digestibility and carcass composition were investigated.

Review of Literature

Nutritive Ratios and their Relationship to Energy

An important concept in nutrition concerns the balance or relative proportion of nutrients in the diet. As any nutrient which is already adequate in the diet increases relative to other essential nutrients, the efficiency of its utilization decreases and its cost is greater in relation to the product produced. If any nutrient is deficient in the diet, other nutrients are present in a relative excess and are used with less than maximum efficiency. Therefore, the efficiency with which an animal can utilize its feed can be affected by a comparative excess or deficiency of one nutrient relative to another in the diet.

Energy intake appears to determine the requirements for most nutrients compatible with maximal efficiency of utilization of the diet for maintenance and production. Kleiber (1945) stated that "a ration is deficient in any food constituent whose addition increases the total efficiency of energy utilization". Crampton (1964) concluded "there is a sound biological basis for considering caloric intake as the fundamental basis for the requirement of most of the known essential nutrients". Thus, energy intake was the basis for the need for all other nutrients.

Guilbert and Loosli (1951) used National Academy of Sciences - National Research Council (NAS - NRC) standards to calculate the daily requirements of digestible crude protein, calcium, phosphorus, carotene, vitamin A, vitamin D, thiamin, riboflavin, niacin and pantothenic acid per unit of Total Digestible Nutrients (TDN) consumed. Requirements for these nutrients, per unit of TDN intake, were similar for several species of farm animals at an equivalent physiological age.

In general, monogastric animals eat to satisfy their need for energy.

Maynard and Loosli (1969) stated that "the largest purpose which food serves is the production of energy for body purposes". Thus nutrient levels based on the energy content rather than the weight of the ration have the advantage of being adjusted in accordance with the work load required to metabolize the energy consumed.

Protein to Energy Nutritive Ratio

Protein and energy appear to be the most significant dietary essentials with respect to nutrition and economics. Davidson (1961) indicated that the provision of protein and energy in the diet could account for about 90 percent of the cost of the diet. It was essential, therefore, to make the best possible use of both the protein and energy by insuring that the amounts provided were optimal in the diet.

Protein and energy requirements of domestic animals are interdependent. Changes in the protein:energy ratio in the diet affect animal performance sooner than do changes in most other nutrient ratios. This resulted in early recognition of the importance of the proper balance between protein and energy. Henry (1904) used the term nutritive ratio to describe the ratio of digestible protein to digestible carbohydrate and fat in the diet.

Crampton (1964) noted that the proportion of protein to energy in rations had undergone little modification since the first feeding standards were established. Guilbert and Loosli (1951) compared protein:energy ratios in rations recommended for growing cattle, sheep and swine at comparable physiological ages. The ratios showed a common pattern of declining need for protein relative to energy as adult weight was approached. In a comparison of the protein requirements for maintenance of adult ruminants and swine, Crampton (1965) found the digestible protein

required per 1000 kcal metabolizable energy (ME) was essentially independent of adult weight or species and averaged about 25 g per 1000 kcal ME. In dairy cows, the variation in the requirement for digestible protein per 1000 kcal ME due to cow size, percent fat in milk or pounds of milk produced by pregnant and/or lactating cows, did not exceed 0.7 percentage units.

Thus it appears that the ratio of digestible protein to digestible energy is similar for adult animals of varying size and species. However, the ratio is affected by physiological age of the animal, reflecting the variation in protein content of the product produced.

Effect of Protein and Energy Intake on Nitrogen Retention

It has been known for some time that withdrawal of some of the carbohydrate or fat from a balanced diet results in an increase in nitrogen excreted in the urine (Werner, 1948). Also, the addition of carbohydrate or fat to diets deficient in energy results in an improvement in nitrogen retention. It has also been shown that addition of energy-yielding nutrients to a diet already adequate in energy results in a considerable increase in nitrogen retention (Munro, 1951). The response of nitrogen retention to increased energy intake is linear and in the order of approximately 2 mg nitrogen per kcal of added energy (Rosenthal and Allison, 1956). This linear response occurs over a wide range of energy levels for diets adequate in protein.

The literature reviewed by Munro (1964) indicated a curvilinear relationship for nitrogen retention in response to additional energy at high levels of energy intake. The response, however, became linear again with increased protein in the diet. Munro concluded that insufficient dietary protein may set an upper limit on the response of nitrogen re-

tention to energy intake.

The question arises whether the level of energy intake influences the ability of the animal to respond to increments of additional protein. The response of nitrogen retention to added protein in the diet is not affected by a wide range of energy intake (Allison and Anderson, 1945). There does appear to be a threshold of energy below which the utilization of higher levels of protein is inhibited (Rosenthal, 1952).

Munro (1964) summarized the observed effects of the interrelationship between protein and energy intake on nitrogen retention. He concluded that nitrogen balance was improved by either an increase in energy intake or an increase in protein intake. However, the increase in nitrogen retention caused by increased energy intake was modified or prevented by inadequate protein intake. Conversely, an increase in protein intake might not be fully effective in inducing increased nitrogen retention because of insufficient energy in the diet.

Effect of Protein Intake on Metabolism

Increased nitrogen retention caused by addition of protein to the diet affects protein metabolism through its influence on the labile protein stores of the body. Munro (1964) pointed out that an increase in protein consumption caused an immediate deposition of labile protein limited to about 5 percent of the total body protein. The labile body protein gained as a result of increased protein intake was rapidly lost when protein intake was decreased.

The labile protein reserve undergoes rapid exchange with the amino acid pool (McFarlane, 1964). In his review, Munro (1964) concluded that the accumulation of labile protein coincided with flooding of the liver with amino acids absorbed from the intestines. Thus, deposition of

labile protein played a part in the retention of amino acids during their absorption. The subsequent breakdown of labile protein released amino acids during the postabsorptive period. This provided a mechanism for maintaining blood amino acid levels between meals.

Effect of Energy Intake on Protein Metabolism

The mode of action of energy intake on protein metabolism was discussed in a review by Munro (1951). At least two mechanisms for sparing protein were distinguishable. One mechanism by which carbohydrate and fat could influence protein metabolism was through their energy yielding properties. However carbohydrate also played a specific role in protein metabolism not shared by fat and related to properties apart from its energy yielding effects.

The action of energy on protein metabolism is not limited to a short period of time after the energy is consumed (Munro, 1954). One or two days may elapse before the energy exerts its full effect on nitrogen balance. Further, the advantageous effects of additional energy on nitrogen balance may occur apart from the consumption of dietary protein. Energy intake exerts its effect on amino acid utilization during the postabsorptive phase and does not influence the capacity of the body to use amino acids during the period of absorption. Very little of the nitrogen retention caused by increasing the energy content of the diet is lost when caloric intake is diminished (Plough et al., 1956). Consequently, the nitrogen retention caused by additional energy is different from that induced by additional protein in that the nitrogen retained as a result of energy intake is stored in a non-labile form.

The protein sparing affect of carbohydrate, apart from its energy yielding properties, occurs for a short time and only when ingested with

protein (Marfatia and Screenivasan, 1960). Munro (1964) concluded that this protein-sparing effect of carbohydrate was dependent on insulin secretion which, with carbohydrate, caused free amino acids to be removed from circulation and deposited in the muscle tissue in the form of labile protein. Because the amino acid supply to other tissues was curtailed, urea production in the liver was diminished.

West et al. (1966) discussed the molecular aspects of the protein-sparing action of carbohydrates. They stated that much of the beneficial effect of carbohydrate was due to its action in increasing the supply of tri-carboxylic acid cycle members which may be aminated and converted to amino acids in the liver, thereby keeping more of the metabolic nitrogen tied up and preventing its excretion as urea. This had an additional benefit to the animal aside from sparing protein. The energy required for the formation of urea from ammonia (4 high-energy phosphate bonds or 35 to 40 kcal per mole of urea formed (Krebs, 1964)) was spared for other metabolic uses.

The Interrelationship Between Protein and Energy in Ruminants

The interrelationship between protein and energy becomes more complex in the ruminant than in monogastric species. Protein and energy as supplied in the diet are modified by the action of the rumen microflora and reach the ruminant host in altered forms. The optimal levels of protein and energy in ruminant diets must be those which in turn enable the rumen microflora to provide the host with the best protein-to-energy ratio.

Several complications arise due to the rumen microflora-host symbiosis. One results from the differences in metabolites provided by the diet (Munro, 1951). The high levels of volatile fatty acids com-

bined with high levels of ammonia and blood urea might be expected to shift the optimal protein-to-energy ratio or alter the mechanisms for their interaction.

A second complication arises from the anaerobic nature of the metabolism of the rumen microflora. Hungate (1966) reported that anaerobes could synthesize about 10 percent of a carbohydrate substrate into protoplasm as compared to 60 to 70 percent for aerobes. The carbohydrate which was not synthesized into microbial material was catabolized into a variety of by-products. In the case of the rumen fermentative process, a large portion of these by-products were in the form of volatile fatty acids which the ruminant could use in its metabolic processes. This energy supply, combined with the higher efficiency of energy utilization for the aerobic host, provided the potential for greater synthesis of protein. However, the aerobic host's protein supply was largely dependent on the amount of protein that could be synthesized from the anaerobic microbial metabolism. Thus, the ruminant might be in a chronic protein deficient state relative to its energy supply.

The dynamic nature of the rumen microflora also complicates the interrelationship between protein and energy in the ruminant. The exponential aspect of the growth of a population of organisms results in different requirements than the maintenance of growth of a single organism (Stanier et al., 1970). Sufficient energy must be provided to keep microbial growth expanding at a fast enough rate to utilize the nitrogen liberated. If microbial growth is too rapid, enhanced protein decomposition in the rumen and the resulting build up of ammonia may result in a loss of nitrogen from the body as was shown by Tagari et al. (1964). A delicate balance exists between two opposing processes; the rate of liberation of ammonia in the rumen and its subsequent synthesis into micro-

bial protein or its excretion as urea in the urine. The extent of each process depends on the relative amounts of protein and energy in the diet and the conditions prevailing in the rumen (Tillman and Sidhu, 1969).

Several authors Bailey and Broster, 1957; Kay et al., 1968; Robertson et al., 1970; Tagari et al., 1964) have studied the effects of feeding different levels of protein in isocaloric rations. They found a curvilinear response in the rate of gain to increasing protein levels. Balch (1967) maintained that as long as the diet was low or lacking in protein, increasing protein levels would result in a linear increase in gain and maximum nitrogen retention. If dietary protein was in excess in relation to energy, increases in protein might result in increases in gain and nitrogen retention but at a lower rate than if energy were not limiting (Stobo et al., 1967). Balch (1967) stated that the curvilinear response to increasing protein resulted from its utilization as an energy source.

Tagari et al. (1964) found that an increase in protein above the recommended levels in rations for sheep resulted in an increased liberation of ammonia. They demonstrated a high correlation between rumen ammonia concentrations, blood urea levels and the excretion of urinary nitrogen. Isocaloric replacement of some of the roughage carbohydrate with starch resulted in an increase in the rate of ammonia liberation in the rumen and a subsequent impairment of protein utilization. They concluded that the starch increased the deamination potential of the rumen, probably due to an increase in the rumen proteolytic activity. Most of the resulting excess ammonia produced was excreted as urea.

The accumulation of rumen ammonia may be reduced by providing greater energy intake (Nicholson and Sutton, 1969). Packett and Groves (1965) showed that the urea pool of sheep consistently decreased during the feeding period. They suggested that an energy source for rumen micro-

organisms stimulated ammonia uptake for microbial protein synthesis and resulted in a net transfer of endogenous urea nitrogen to the rumen. The increase in the urea pool during fasting reflected a decrease in microbial protein synthesis due to the absence of a readily available energy source in the rumen.

In some instances, an accumulation of rumen ammonia may result in an increase in nitrogen retention. Several authors have reported anomalies in the correlation between rumen ammonia, blood urea and nitrogen loss as reported by Tagari et al. (1964). Hogan (1961) showed that a decrease in rumen pH restricted the absorption of ammonia from the rumen, thus allowing greater concentration of rumen ammonia without a concomitant nitrogen loss. In a review of nitrogen utilization by the ruminant, Waldo (1968) stated that the permeability of the rumen wall to ammonia was inversely related to urine flow. Increased retention of ammonia in the rumen resulted in greater protein synthesis and cellulose digestion due to a more active microbial population (Moir and Harris, 1962).

Broster et al. (1969) studied the effects of energy intake on the utilization of protein in growth and lactation. They concluded that the protein requirements for a given rate of production depended on the energy intake. Elliott et al. (1964) reached a similar conclusion from the results of feeding trials, using three levels of digestible crude protein fed at three energy levels. They found that rate of gain showed a greater response to increasing protein at the higher levels of energy intake. They concluded that protein requirements could be defined only when the amounts of digestible energy consumed were known.

Stobo et al. (1967) studied the effects of protein and energy intake on weight gain in young calves. Their study indicated that at a

given protein intake, different growth rates could be obtained depending on the energy intake. If protein was increased with no increase in energy, growth rate continued to rise but with diminishing response per unit of extra protein. If energy was increased, however, the response to extra units of protein did not decrease.

Clanton et al. (1965) studied the effects of supplementing diets for range cattle with protein and energy. They indicated that when protein was limiting there was no advantage in supplying additional energy without increasing the protein intake. When energy was limiting, increasing energy intake was more effective in increasing nitrogen retention than increasing protein intake.

Gordon and Forbes (1970) studied the associative effects of the level of energy and protein intake with the dairy cow. There was a greater partitioning of additional energy toward milk energy output with a high protein level than with a low protein level. They found the efficiencies of utilization of metabolizable energy for milk output to be 63 percent and 50 percent for the high and low protein diets, respectively. These workers concluded "the milk yield at any level of energy intake, and the response in milk yield and composition to changes in energy intake, depend upon the level of protein intake".

Andrews and Orskov (1970a) studied the influence of protein concentration of the diet and feeding level on the rate of liveweight gain of early-weaned lambs. They found highly significant interactions between the effects of feeding level and protein concentration. Growth rates showed a greater response to higher protein concentration as the feeding level increased. They suggested that over the range of 16 to 40 kg body weight, optimum growth rate occurred with 17, 15 and 11 percent dietary crude protein levels when digestible energy intakes were 3.0, 2.6 and 2.1 Mcal per day, respectively.

Norton et al. (1970) studied the effects of protein and energy intake on the composition of liveweight gain of lambs. They reported a decrease in fat content of empty body weight and an increase in water and protein content as the dietary protein concentration increased. Andrews and Orskov (1970b) found a linear increase in fat and nitrogen deposition in lambs with increasing feeding level. In lambs slaughtered at 27.5 kg there were linear increases in the rate of protein deposition and decreases in fat deposition with increases in the concentration of crude protein in the diet. This effect was particularly marked at the high level of feed intake. In lambs slaughtered at 40 kg, the effect of increasing dietary protein concentration on protein deposition was curvilinear.

Experiments at the University of Alberta

Experiments were conducted to study the effects of feeding rations with different protein to energy ratios at different energy levels. The parameters investigated included growth, feed utilization and carcass composition of Holstein bulls and steers.

Experimental

Eighteen Holstein bulls and nine Holstein steers were purchased at the Edmonton Public Stock Yards in April 1970. Their weight ranged from 90 to 240 kg with an average weight of 170 kg. One heavy bull, one light bull and one steer were randomly assigned to each of nine treatment combinations. The animals were tied in individual stalls at the Dairy Cattle Research Unit, The University of Alberta, Edmonton Research Station.

All animals were weighed individually between 9 A.M. and 10 A.M. each Wednesday after being without water for at least 3 hours and before receiving their morning feed.

Rations and Feeding

Three isocaloric rations were formulated to contain low (7.95%), medium (11.95%) and high (15.95%) levels of digestible crude protein, using average values for the feeds in NRC (1970) tables. These rations contained 8.95, 12.99 and 17.02 percent crude protein by analysis (Table 1). Each ration was fed at a high, medium or low level of energy based on animal metabolic weight ($W_{kg}^{3/4}$). The three energy levels chosen were those which would produce daily gains of 0.8, 1.0 and 1.2 kg per day based on the equation of Garrett et al. (1959). This equation, $DE = 74.5 W^{3/4} (1.0 + 0.59 g)$ (where DE = digestible energy, W = weight in

Table 1

Formulation of experimental rations

Ingredients (kg)	Protein level		
	Low	Medium	High
Barley	90.0	78.5	67.0
Soybean meal	0.0	11.5	23.0
Beet pulp	8.5	8.5	8.5
Limestone	1.0	1.0	1.0
Cobaltized-iodized salt	0.5	0.5	0.5
Vitamin A, D and E mix ¹	0.09	0.09	0.09
TOTAL	100.0	100.0	100.0
Analysis (on as-fed basis)			
Dry matter (%)	86.50	86.80	87.10
Crude protein (%)	8.95	12.99	17.02
Gross energy (Mcal/kg)	3.84	3.87	3.91

¹ Vitamin A, D and E mix: vitamin A - 10,000 I.U./g; vitamin D - 1,000 I.U./g; vitamin E - 100 I.U./g.

pounds and g = daily gain in pounds), resulted in energy levels of 318, 358 and 398 kcal gross energy per day per unit of metabolic weight. The daily allotment of crude protein and gross energy fed to the nine treatment groups per unit metabolic weight is shown in Table 2.

Feeding levels were adjusted each Wednesday based on the weekly weight of the animal. The animals were fed twice daily at 9 A.M. and 3 P.M. Water and mineral mixture of 50 percent cobaltized-iodized salt and 50 percent calcium phosphate were available free-choice.

Metabolism Studies

Metabolism studies were conducted on each of the 27 experimental animals between 50 and 70 days after the start of the feeding trial. The metabolism trials were carried out in three sections. Nine animals, one from each treatment group, were used in each section. Heavy bulls, light bulls and steers were on trial in that order. A 4-day adjustment period preceded the 5-day collection period. The animals on trial were not weighed and their level of feed was not adjusted during the metabolism trial.

Total feces and urine were collected from each animal during the 5-day collection period. Urine collection funnels were constructed similar to those described by Kehoe (1969). The urine was collected through the rubber funnel held in place with a harness and conveyed to 10-liter nalgene carboys which were suspended in the gutter. Urine output was measured at 12 hour intervals. At each measurement total volume was recorded and 5 percent was retained. These samples were stored in 1-liter nalgene bottles with 5 ml of 50 percent (v/v) sulfuric acid. The ten urine samples from each animal were mixed and stored at 4 C for future analysis.

Table 2

Protein and energy intake per unit metabolic weight

Feeding level	Protein level			
	low	medium	high	
	<u>Protein intake (grams/kg W3/4/day)</u>			average
low	7.33	10.64	13.94	10.63
medium	8.26	11.99	15.71	11.98
high	9.20	13.35	17.49	13.35
average	8.26	11.99	15.71	11.98
	<u>Energy intake (kcal/kg W3/4/day)</u>			
low	315	317	320	318
medium	355	357	361	358
high	395	398	402	398
average	355	357	361	357

Fecal collection bags were similar to those described by Noller et al. (1959). Six-mil polyethylene bags, 85 cm by 40 cm, were prepared as shown in Figure 1. The bag was fastened over the animal's back to the urine collection harness by means of a nylon cord threaded through 2 grommets placed in the top of the bag. The front opening of the bag was held against the animal by nylon cords taped around the opening and tied between the legs to the urine collection harness. The bag was reinforced with polyethylene tape around the tail opening and at the grommets. These bags could hold about 7 kg of feces and could be used several times.

Fecal output was measured over 18 hour intervals. At each measurement total weight was recorded and 5 percent was retained and frozen. The fecal samples from each animal were mixed and stored in polyethylene bags at -5 C for subsequent analysis.

On each day of the metabolism trial, feed samples were taken from each of the three rations. The five samples from each ration were mixed and stored in polyethylene bags for subsequent analysis. This procedure was repeated for each section of the metabolism trial. Thus there were three separate samples for each ration; one from each metabolism trial conducted.

Slaughter Data and Carcass Measurements

The animals were slaughtered after they had gained 75 to 150 kg. They were weighed at the Dairy Cattle Research Unit before being trucked to Gainers Packing Plant for slaughter. Feed and water were withheld for a 12-hour period before weighing. The viscera and vital organs were examined at slaughter and abnormalities recorded. Kidney fat was removed from the left half of the carcass and weighed. Warm carcass weight

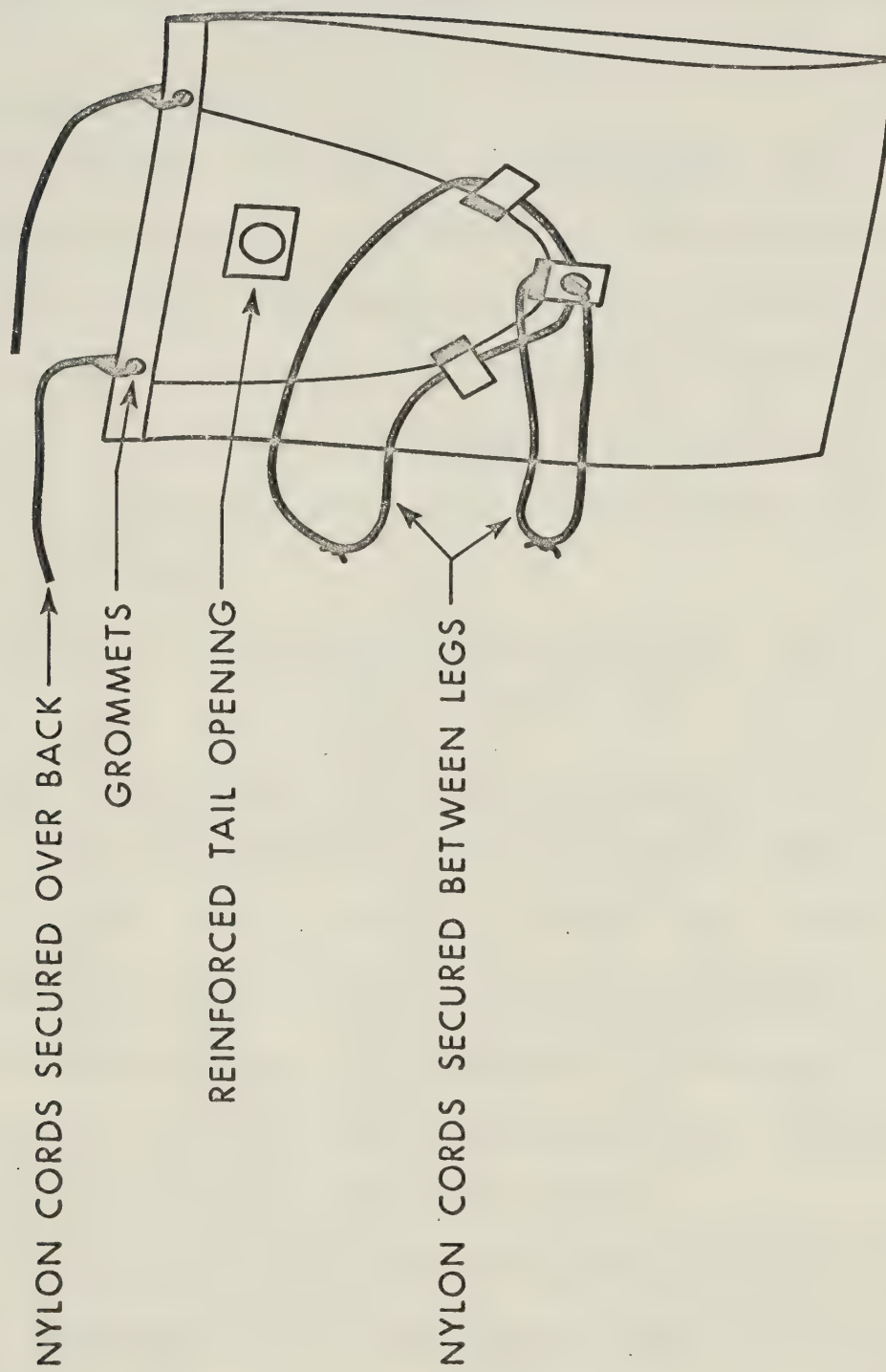


Figure 1 Fecal Collection Bag

was recorded. The carcasses were graded by Canada Department of Agriculture standards 24 hours after slaughter. The cross-sectional area of the longissimus dorsi muscle and the fat thickness was measured between the 11th and 12th ribs. The 9-10-11 rib section was removed from the right half of the carcass, weighed and frozen for future analysis.

Analytical Procedures

Fecal samples were dried in a forced-draught oven at 70 C for 48 hours and pulverized in a Waring blender. Feed samples were ground in a laboratory mill. Dry matter and nitrogen in feed and fecal samples and nitrogen in urine samples were determined by AOAC (1965) methods. Dry matter in urine was determined by freeze-drying. Gross energy in feed, feces and freeze-dried urine was determined in a Parr Oxygen Bomb Calorimeter.

The tenth rib was dissected from the 9-10-11 rib section by cutting on lines crowding the 9th and 11th ribs. The end of the tenth rib joint was discarded at a distance proportional to the width of the rib section along the halved vertebra as shown in Figure 2. The remainder of the 10th rib section was divided into separable fat, lean and bone. Dry matter content of the separable fat and lean was determined by freeze-drying. Ether extract of the separable lean was determined with a Goldfish fat extraction apparatus. Nitrogen was determined on the residue by AOAC (1965) methods.

The data were statistically analyzed by analysis of variance on an IBM 360 computer in the Department of Computing Science, University of Alberta. The analysis of variance program (number CS017) designed by Harley (1962) was obtained from the University of Alberta, Department of Computing Science Program Library. Duncan's new multiple range

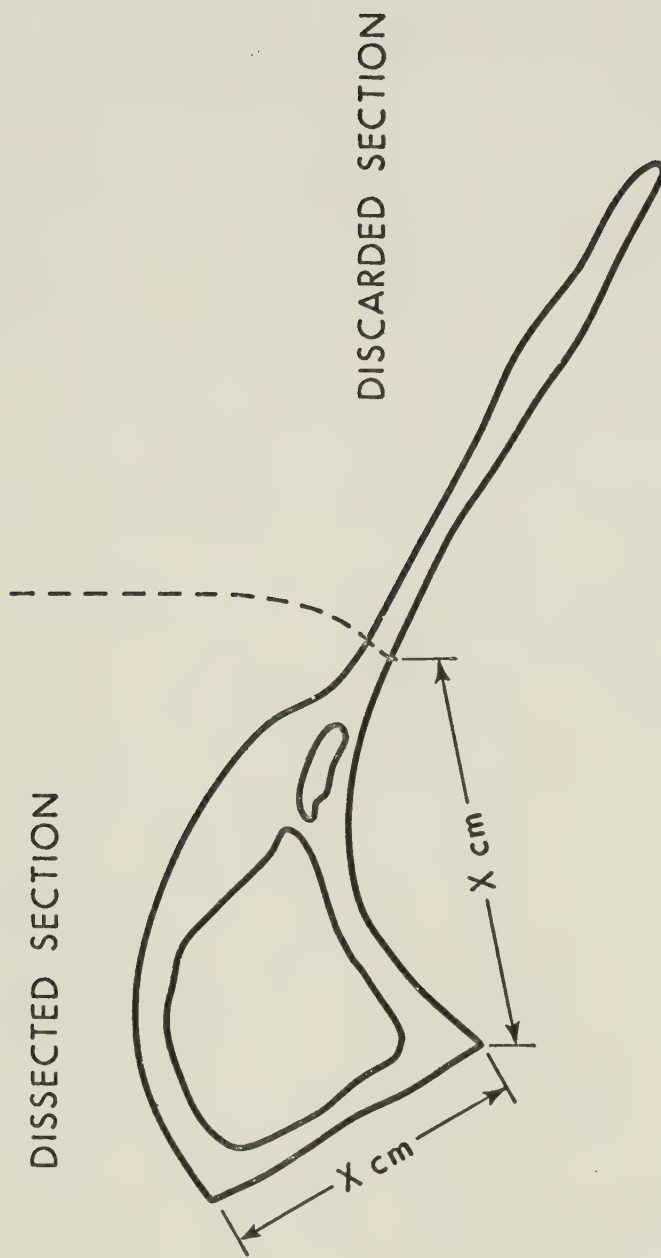


Figure 2 10th Rib Section

test (Steel and Torrie, 1960) was used to compare differences between means.

Analysis of variance tables listing the source of variation, degrees of freedom, sums of squares and mean squares are recorded in the appendix.

Results and Discussion

Average Daily Gain

Animals fed 318, 358 and 398 kcal gross energy per unit metabolic weight per day (low, medium and high energy levels) gained an average of 0.84, 1.15 and 1.32 kg per day, respectively (Table 3). Those receiving the low energy diet gained significantly less ($P < 0.01$) than the animals fed the medium level of energy. Animals fed the medium level of energy gained significantly less ($P < 0.01$) than animals receiving the high energy diet. The daily gains compared favorably with the anticipated gains of 0.80, 1.00 and 1.20 kg per day for low, medium and high energy, respectively, based on the equation of Garrett et al. (1959).

The response in daily gain to increased energy intake was not linear. An increase in energy intake from 318 to 358 kcal gross energy per unit metabolic weight per day increased the average daily gain by 0.31 kg per day. A further increase in energy of 40 kcal/W^{3/4}/day increased daily gains only 0.17 kg on the average.

Animals on the low (8.95%), medium (12.99%) and high (17.02%) crude protein diets gained an average of 0.87, 1.18 and 1.26 kg per day, respectively (Table 3). The animals receiving the low protein diet gained significantly less ($P < 0.01$) than those fed the medium or high protein diets.

The response in increase in daily gain to increasing protein intake was not linear. An increase in crude protein intake from 8.26 to 11.99 grams per unit metabolic weight per day increased the average daily gain by 0.31 kg per day, as compared to an increase in gain of 0.08 kg per day resulting from a further increase of 3.73 grams crude protein per unit metabolic weight per day.

Table 3

Average weight gain and feed utilization

Energy level	Dietary crude protein level (%)			
	8.95	12.99	17.02	
	Average daily gain (kg)			average
low	0.63	0.94	0.95	0.84 ^a
medium	0.93	1.20	1.32	1.15 ^b
high	1.04	1.40	1.52	1.32 ^c
average	0.87 ^a	1.18 ^b	1.25 ^b	
	Average dry matter intake (kg) per kg gain			average
low	5.4	4.4	4.2	4.7 ^a
medium	4.7	3.7	3.6	4.0 ^b
high	4.7	4.0	3.7	4.1 ^b
average	4.9 ^a	4.0 ^b	3.8 ^b	
	Average gross energy intake (Mcal) per kg gain			average
low	23.9	19.4	18.8	20.7 ^A
medium	21.4	16.6	16.2	18.1 ^B
high	21.0	16.5	18.0	18.5 ^B
average	22.1 ^a	18.0 ^b	17.2 ^b	
	Average crude protein intake (g) per kg gain			average
low	588	651	816	675 ^A
medium	489	559	705	585 ^B
high	490	605	719	605 ^B
average	514 ^A	605 ^B	747 ^C	

a b c means in the same group which are followed by a common superscript are not significantly different (P < 0.01).
A B C means in the same group which are followed by a common superscript are not significantly different (P < 0.05).

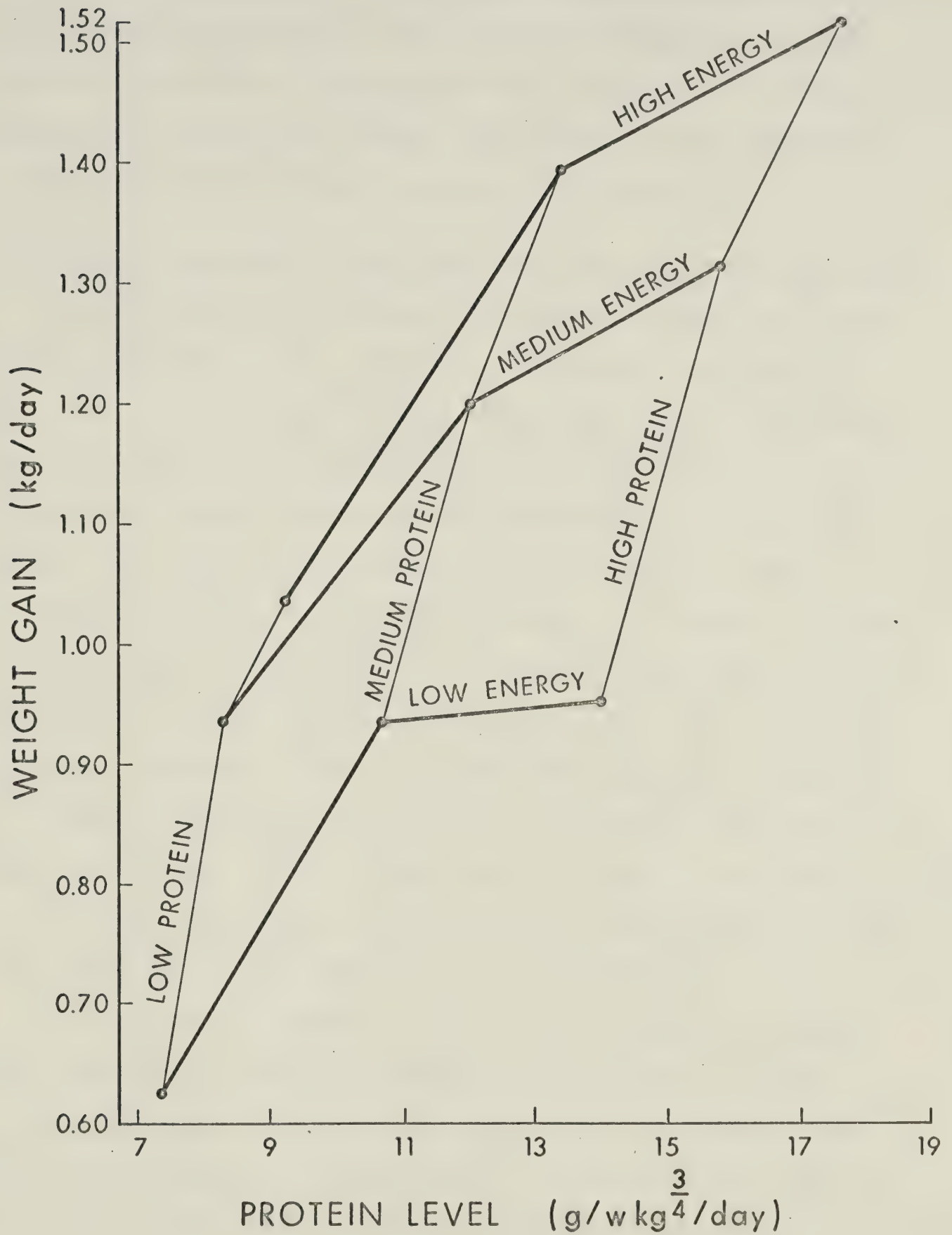
Kay et al. (1968) fed all-concentrate rations containing 11, 14 and 17 percent crude protein to Friesian steers on an ad libitum basis. The steers in the 150 to 200 kg weight range gained 0.85, 1.08 and 1.12 kg per day on the low, medium and high protein diets, respectively. These weight gains and the pattern of response to increasing dietary protein levels were very similar to the results obtained in the present study.

The animals with medium and high energy intake showed a greater response to the high protein level than the animals with low energy intake (Figure 3). Similarly, animals in the medium and high protein groups showed a greater response to high energy intake than the animals in the low protein group. The interaction of protein and energy on average daily gain was not statistically significant ($P < 0.05$).

The relationship between protein and energy intake on liveweight gain found in this experiment was similar to that reported elsewhere. In experiments with African breeds of cattle fed at near maintenance levels, Elliott et al. (1964) found that increasing the protein level without increasing energy intake resulted in an increased loss in weight gain of animals fed below the maintenance level. With animals fed at different levels above maintenance, however, increasing protein resulted in an increased rate of gain. The increased daily gain due to higher protein levels was greater at the higher energy levels. Broster et al. (1969) and Stobo et al. (1967) found that if protein intake was increased without increasing energy intake, rate of gain increased but with diminishing response per unit of additional protein.

Heavy bulls, light bulls and steers gained 1.30, 1.15 and 0.86 kg per day, respectively. The steers gained significantly less ($P < 0.01$) than the two classes of bulls. The interactions of sex on protein level and on energy level were not significant ($P < 0.05$). In studies to deter-

Figure 3 The Effect of Dietary Crude Protein and Energy
on Average Daily Gain



mine the effects of castration and dietary protein level on growth in beef cattle, Robertson et al. (1970) found a significant reduction in gain due to castration. The change in rate of gain, due to different crude protein levels (11.5, 14.3 and 19.8 percent), in bulls compared to steers was not significant ($P < 0.05$) in their study.

Utilization of Dry Matter, Crude Protein and Gross Energy for Weight Gain

The efficiency of utilization of dry matter for weight gain was affected by the energy level. Dry matter consumed per kg gain was 4.7, 4.0 and 4.1 kg for the low, medium and high energy groups, respectively (Table 3). The animals in the low energy group required 16 percent more dry matter per kg gain than the animals in the medium and high energy groups. This difference was statistically significant ($P < 0.01$).

Protein level also affected the efficiency of dry matter utilization for weight gain. The animals on the low, medium and high protein rations required 4.9, 4.0 and 3.8 kg dry matter per kg weight gain, respectively (Table 3). The animals in the low protein group required an average of 26 percent more dry matter per kg gain than the animals in the medium and high protein groups. This difference was statistically significant ($P < 0.01$).

The interaction between protein and energy levels on the efficiency of dry matter utilization (Table 3) was not significant ($P < 0.05$).

Bulls and steers required 4.2 and 4.4 kg of dry matter per kg of gain, respectively. This difference was not significant ($P < 0.05$).

The efficiency of utilization of gross energy for weight gain was significantly affected by energy intake ($P < 0.05$) and protein level ($P < 0.01$). Animals in the low energy group required an average of 13 percent more gross energy per kg gain than animals in the medium and high energy groups (Table 3). The animals on low protein required an average

of 25 percent more energy per kg gain than the animals on the medium and high protein rations (Table 3). Gardner (1968) found that the efficiency of caloric utilization for weight gain was not significantly affected by protein levels varying from 12 to 16 percent crude protein.

The interaction of protein and energy on the efficiency of energy utilization was not significant ($P < 0.05$).

The efficiency of utilization of crude protein for weight gain was affected by the energy level. Animals in the low, medium and high energy groups consumed 675, 586 and 605 grams of crude protein per kg gain (Table 3). The animals on low energy consumed significantly more ($P < 0.05$) crude protein per kg gain than the animals on the medium and high energy diets.

Increasing the protein level of the ration resulted in an increase in the protein consumed per kg weight gain. Animals in the low, medium and high protein groups consumed 514, 605 and 747 g crude protein per kg gain (Table 3). All differences were significant ($P < 0.05$). Gardner (1968) also reported a significant increase in the protein used per unit weight gain with increasing protein levels in the ration.

There was no significant interaction ($P < 0.05$) between protein and energy on the efficiency of protein utilization for weight gain (Table 3).

There was no significant difference ($P < 0.05$) between the efficiency of protein utilization for weight gain for bulls versus steers.

From these results it is evident that increasing energy intake resulted in an increase in daily weight gain regardless of the protein level being fed. Also, the efficiency of utilization of the ration dry matter, gross energy and crude protein for weight gain was higher at the high energy levels. Increasing the protein level of the ration from 8.95 to 12.99 percent was effective in increasing liveweight gain and the eff-

iciency of utilization of dry matter and gross energy for weight gain. This effect of protein was evident regardless of the energy level being fed. Increasing the protein content of the ration from 12.99 to 17.02 percent did not appreciably improve weight gain or the efficiency of utilization of dry matter and gross energy for weight gain.

Coefficients of Apparent Digestibility and True Digestibility of Protein

The average dry matter digestibility for all treatment groups was 81 percent (Table 4). Increasing the energy intake or increasing the protein concentration of the ration did not have a significant effect ($P < 0.05$) on dry matter digestibility in this experiment.

In studies with sheep, Andrews and Orskov (1970a) and Robinson et al. (1970) found no significant differences in dry matter digestibility with changes in energy intake. In both experiments, energy intake was altered by changing the daily dry matter consumption by a factor of metabolic weight.

Gordon and Forbes (1970), Kay et al. (1970) and Stone and Fontenot (1965) found that dry matter digestibility increased significantly with increases in energy intake in rations fed to cattle. These researchers increased the energy intake by increasing the energy concentration of the ration while holding dry matter intake constant.

Several workers (Blaxter, 1967; McDonald et al., 1966 and Maynard and Loosli, 1969) have noted that dry matter digestibility is decreased with increasing dry matter intake of rations fed to ruminants. As there was no reduction in dry matter digestibility with increasing feed intake in the present experiment, nor in the experiments of Andrews and Orskov (1970a) and Robinson et al. (1970), it would appear that the increase in energy consumption had a beneficial effect on dry matter digestibility.

Table 4

Coefficients of apparent digestibility and true protein digestibility (%)

Energy level	Dietary crude protein level			
	8.95	12.99	17.02	
<u>Average dry matter digestibility</u>				average
low	77	83	83	81 ^a
medium	80	82	83	82 ^a
high	79	84	82	81 ^a
average	79 ^a	83 ^a	82 ^a	
<u>Average apparent gross energy digestibility</u>				average
low	76	82	81	80 ^a
medium	79	81	82	81 ^a
high	77	80	81	79 ^a
average	77 ^a	81 ^a	81 ^a	80
<u>Average apparent crude protein digestibility</u>				average
low	61	74	84	73 ^a
medium	69	78	83	77 ^a
high	66	76	83	75 ^a
average	65 ^a	76 ^b	83 ^b	75
<u>Average true protein digestibility¹</u>				average
low	88	93	97	93 ^a
medium	97	97	96	96 ^a
high	94	95	96	95 ^a
average	93 ^a	95 ^a	96 ^a	95

a b c means of each treatment group followed by a common superscript are not significantly different (P < 0.01).

¹ metabolic fecal nitrogen was calculated as 2.811 g protein per 100 g dry matter (Blaxter and Mitchell, 1948).

Gardner (1968) and Gordon and Forbes (1970) found no change in dry matter digestibility with changes in the protein concentration of rations fed to dairy cattle. Average dry matter digestibility was not increased by increasing the protein level of rations fed to sheep (Andrews and Orskov, 1970). Kay et al. (1968) and Putnam (1966) found an increase in organic matter digestibility at higher levels of protein intake in rations fed to cattle. The rations used by Putnam (1966) were high in roughage concentration with dry matter digestibility coefficients of around 60 percent. Rations fed by Kay et al. (1968) were very similar to those used in this experiment. All concentrate barley-based rations used by Kay et al. (1968) with crude protein levels of 11, 14 and 17 percent resulted in dry matter digestibilities of 72, 78 and 81 percent respectively when fed to Friesian steers. The inconsistencies reported in the literature regarding the response of dry matter digestibility to changes in the protein level of the ration indicates the involvement of other factors, such as variations in the amount of roughage in the diet, which may influence dry matter digestibility to as great an extent as the variation in protein level.

The apparent digestibility of gross energy was not significantly affected ($P < 0.05$) by the energy intake or the protein level of the rations fed in this experiment. The apparent digestibility of gross energy averaged 80 percent for the 9 treatment combinations (Table 4).

Kay et al. (1970) and Stone and Fontenot (1965) found an increase in gross energy digestibility with increasing energy concentration of rations fed to cattle. Kay et al. (1970) and Putnam et al. (1966) found that gross energy digestibility increased with increasing protein level of the ration. Andrews and Orskov (1970) found an increase in gross energy digestibility with increasing protein intake at a high

feeding level. At medium and low levels of feed intake, their results showed no significant change ($P < 0.05$) in gross energy digestibility with changes in the protein level of the diet. Changes in the energy intake did not affect gross energy digestibility in their experiments.

These variations in the response of apparent gross energy digestibility indicate that factors other than changes in the protein and energy level of the diet may be involved. Rations used by Stone and Fontenot (1965) had a wide range of crude fibre levels. The high, medium and low energy diets contained 12, 17 and 23 percent crude fibre, respectively. The decreasing crude fibre content of the rations with increasing energy level may have been as responsible for the increase in gross energy digestibility as the increase in energy levels. The low protein rations used by Putnam et al. (1966) contained 17.0 percent crude fibre while the high protein rations contained 11.5 percent crude fibre. The difference in crude fibre content between the rations fed to the low and high protein groups may have been responsible for the higher gross energy digestibility associated with the higher protein group.

In this experiment, there were no detectable significant differences ($P < 0.05$) in the apparent digestibility of crude protein caused by changes in energy intake. There was a significant increase ($P < 0.01$) in the apparent digestibility of crude protein with increasing protein level of the ration. Rations containing 8.95, 12.99 and 17.02 percent crude protein had apparent crude protein digestibilities of 65, 76 and 83 percent, respectively (Table 4). The apparent digestibility of crude protein for animals on the low protein diet was significantly less ($P < 0.01$) than for animals on the medium or high protein diets.

The apparent digestibility of crude protein may increase with increasing crude protein intake even though the percentage of dietary protein which is actually digested remains the same. Metabolic fecal nitrogen is a function of feed intake. If feed intake remains constant, increasing the protein intake results in an increase in fecal nitrogen output. Since the metabolic fecal nitrogen fraction of the total fecal output does not increase, the apparent digestibility of the dietary crude protein will show an increase (Maynard and Loosli, 1969). Andrews and Orskov (1970), Gordon and Forbes (1970), Kay et al. (1968), Kay et al. (1970) and Putnam (1966) all found that increasing the dietary crude protein level of the ration increased the apparent digestibility coefficients for crude protein.

True protein digestibility did not increase significantly ($P < 0.05$) with increasing protein intake (Table 4). It appears that the dilution of metabolic fecal nitrogen with increasing protein intake, as discussed above, must have, at least in part, accounted for the significant increase in apparent digestibility of protein with the medium and high protein diets.

In this experiment, there was no detectable improvement in the digestibility of the rations due to increases in the energy intake or protein level of the diet. All concentrate rations of the type used in this experiment are of a highly digestible nature. Thus the capacity of the animals digestive system or the rate of flow of digesta through the rumen would not be limiting factors to digestion in this experiment.

Nitrogen Balance Data

There was no significant increase ($P < 0.05$) in fecal nitrogen excretion of animals with increasing nitrogen intake (Table 5). There

Table 5

Nitrogen balance data

Energy level	Protein level (%)			average
	8.95	12.99	17.02	
<u>Nitrogen intake (grams/day)</u>				
low	56	97	137	97 ^a
medium	75	113	170	119 ^b
high	85	141	207	144 ^c
average	71 ^a	117 ^b	172 ^c	120
<u>Fecal nitrogen (grams/day)</u>				
low	22	25	22	23 ^a
medium	23	25	30	26 ^b
high	28	34	36	32 ^c
average	24 ^a	28 ^a	30 ^a	27
<u>Urinary nitrogen (grams/day)</u>				
low	15	39	44	35 ^a
medium	22	32	39	31 ^a
high	17	36	55	36 ^a
average	18 ^a	36 ^a	46 ^a	33
<u>Apparent Nitrogen retention (grams/day)</u>				
low	19	33	71	41 ^a
medium	30	56	102	63 ^a
high	39	71	117	76 ^a
average	30 ^a	53 ^b	95 ^c	60
<u>Nitrogen retained (as % of apparent digestible nitrogen)</u>				
low	57	47	60	55 ^a
medium	61	65	72	66 ^a
high	71	65	66	68 ^a
average	63 ^a	59 ^a	66 ^a	63

a b c means in the same group which are followed by a common superscript are not significantly different ($P < 0.01$)

was, however, a significant increase ($P < 0.01$) in the fecal nitrogen output of animals with each increase in the level of energy. This increase was probably due to an increase in the metabolic fecal nitrogen fraction caused by the increase in dry matter consumption associated with increasing energy intake. Stone and Fontenot (1965) found that total fecal nitrogen excretion values were similar for three levels of energy intake. These researchers increased energy intake by increasing the energy concentration of the diet and holding consumption constant.

Urinary nitrogen excretion of animals on low, medium and high protein intakes was 18, 36 and 46 grams per day, respectively (Table 5). These differences were not statistically significant ($P < 0.05$) due to the large variation in urinary nitrogen excretion within treatment groups. There were no statistically significant differences ($P < 0.05$) detectable in urinary nitrogen excretion due to changes in energy intake. Robinson et al. (1970) found urinary nitrogen output was lower on the high compared to the low energy diet. They reasoned that this trend was accentuated by the lower intake of digestible crude protein by animals on the high energy diets.

Apparent nitrogen retention was 41, 63 and 76 grams per day for animals on the low, medium and high energy levels, respectively (Table 5). These differences were not statistically significant ($P < 0.05$). Animals on the low, medium and high protein diets had apparent nitrogen retention values of 30, 53 and 95 grams per day, respectively. These differences were statistically significant ($P < 0.01$).

Lofgreen et al. (1951) showed that on a low protein intake, an increase in energy consumption resulted in a marked increase in the nitrogen retention of the growing calf. These researchers increased the energy consumption by increasing feed intake. The protein level was

held constant by lowering the protein concentration of the experimental rations. Gordon and Forbes (1970) presented data showing that the level of nitrogen retained was significantly increased by an increase in the energy level of diets fed to lactating cows. The level of protein intake did not significantly affect nitrogen retention in their experiment. Matsushima et al. (1957) found no significant change in nitrogen retention due to varying levels of protein or energy intake.

Comparisons of the response of nitrogen retention to different protein and energy levels as recorded in the literature must be conducted with caution. If energy or protein levels are adjusted by changing the ration ingredients or their levels (as was done by Matsushima et al. (1957)) there is a possibility of associative effects occurring between the ration components which are not directly related to the protein or energy levels of the diets as was shown by Asplund and Harris (1971). If energy level is adjusted by changing the feed intake as was done by Lofgreen et al. (1951), the increase in dry matter consumption could increase the excretion of metabolic fecal nitrogen and consequently affect apparent nitrogen retention.

The percent of apparent digestible nitrogen which was retained (Table 5) was not significantly affected by the protein levels used in this experiment. The efficiency with which digestible protein was retained by the animal increased from 55 to 68 percent for animals with low and high energy intakes, respectively. This increase was not significant due to the large variation in nitrogen retention of animals within treatment groups.

Slaughter and Carcass Data

The animals in this experiment were slaughtered after they had gained

75 to 150 kg. The average initial weight, slaughter weight, weight gains and days on feed for the 9 treatment groups are given in Table 6. There were no significant differences ($P < 0.01$) among the average initial weights or among the average slaughter weights of the animals in the 9 treatment groups. The animals on the low energy and the low protein diets gained significantly less ($P < 0.01$) than the animals in the other treatment groups even though their feeding period was longer.

Average initial weight, slaughter weight and weight gain was 193, 322 and 129 kg, respectively, for bulls and 124, 233 and 109 kg, respectively, for steers. The average initial weight, slaughter weight and weight gain for bulls was significantly higher than for steers ($P < 0.01$). The feeding period for the steers was longer on the average than for bulls (129 days as compared to 109 days).

The incidence of animals with abscessed livers was low in this trial. Two animals (7.4 percent) had abscessed livers. Their daily weight gain did not appear to be affected when compared to the gains of animals in similar treatment groups. Foster and Woods (1970), Harvey et al. (1968) and Rowland (1970) reported the incidence of liver abscesses of animals slaughtered for beef. On the average, 22 to 33 percent of the cattle examined by these authors had liver abscesses. They reported that the incidence was higher in cattle fed all-concentrate rations than in cattle reared on diets containing roughage.

All carcasses graded either Canada Manufacturing or Canada Utility (Class 1). There was an increase in the number of animals which graded Canada Utility in the high energy and high protein groups. Of the 9 animals receiving high energy diets, 7 graded Canada Utility. Of the 9 animals on the low energy diets, only 3 graded Canada Utility. Similar differences in grade were observed between animals on high and low

Table 6

Initial weight, final weight, weight gain and days on feed

Energy level	Protein level (%)			
	8.95	12.99	17.02	
<u>Average initial weight (kg)</u>				average
low	141	171	165	159 ^a
medium	172	165	174	170 ^a
high	170	189	187	182 ^a
average	161 ^a	175 ^a	175 ^a	170
<u>Average slaughter weight (kg)</u>				average
low	229	287	285	267 ^a
medium	287	287	310	294 ^a
high	288	325	331	315 ^a
average	268 ^a	300 ^a	308 ^a	300
<u>Average weight gain (kg)</u>				average
low	88	117	120	108 ^a
medium	116	123	136	125 ^b
high	118	137	144	133 ^b
average	107 ^a	125 ^b	133 ^b	122
<u>Average days on feed</u>				average
low	140	126	128	131
medium	126	105	105	112
high	117	100	96	104
average	128	110	110	116

^a ^b means in the same group which are followed by a common superscript are not statistically significantly different ($P < 0.01$).

protein diets. Six of the 9 animals on the high protein diets graded Canada Utility compared to 3 of the 9 animals on the low protein diets. Carcasses receiving the Canada Utility grade require a thicker, smoother and more evenly distributed fat cover than those which grade Canada Manufacturing (Canada Department of Agriculture, 1964).

The dressing percentage, expressed as the warm carcass weight as a percent of liveweight, averaged 54 percent for all treatment groups. Animals in the low, medium and high protein groups had average dressing percentages of 53, 55 and 55, respectively. Animals in the low protein groups had a significantly lower ($P < 0.05$) average dressing percentage than animals in the medium and high protein groups. The level of energy intake did not significantly affect the dressing percentage in this experiment ($P < 0.05$). There was no significant difference between the dressing percentage of bulls and steers in this experiment ($P < 0.05$).

Robertson et al. (1970) fed rations containing 11, 15 and 20 percent crude protein to bulls and steers from 80 kg initial weight to 420 kg slaughter weight. There was no significant difference in the dressing percentage between the three protein groups in their experiment. The steers in their experiment had a significantly higher ($P < 0.01$) dressing percentage than the bulls. Field (1971) and Hendrick et al. (1969) presented data indicating that the dressing percentage for bulls and steers was similar.

Estimates of Separable Carcass Fat

Several carcass parameters were measured in an attempt to establish whether there were differences in the fat and lean content of the carcasses. Differences in the amount of fat in the carcasses were indicated by measurements of kidney fat, separable fat of the 10th rib section, and average depth of fat cover over the longissimus dorsi muscle between the 11th and

12th ribs.

The fat surrounding the right kidney and the pelvic fat from the right carcass side was extracted from the carcass at the time of slaughter, weighed and recorded as kidney fat. There was an increase in kidney fat with increasing energy intake. Animals receiving low, medium and high energy diets had, on the average, 1.15, 1.26 and 1.38 kg of kidney fat, respectively (Table 7). These differences were not statistically significant ($P < 0.05$). Kidney fat showed the greatest response to increasing energy intake in the animals fed the low protein diets. Kidney fat of animals receiving medium and high protein diets increased very little with increasing energy consumption (Table 7). Animals receiving low, medium and high protein diets had, on the average, 1.37, 1.16 and 1.26 kg of kidney fat, respectively. These values were not significantly different ($P < 0.05$).

Kidney fat has been used by several authors as an indirect estimate of the fat content of beef carcasses. Murphey et al. (1960) used percent kidney fat along with three other easily measurable carcass variables to estimate the percent of boneless retail cuts of beef carcasses. Percent kidney fat was negatively correlated with the percent of boneless retail cuts. Fitzhugh et al. (1965) used the weight of kidney fat to develop prediction equations for the weight of boneless roast and steak meat in beef carcasses. They found that the relation between kidney fat weight and percent boneless roast and steak meat was negative and highly significant. This highly significant ($P < 0.01$) negative correlation (-0.69) between kidney fat weight and the percent of boneless roast and steak meat was attributed to the close relationship between weight of kidney fat and total carcass fat. Epley et al. (1970) used kidney fat plus heart fat in prediction equations for per-

Table 7

Carcass composition

Energy level	Dietary crude protein level (%)			
	8.95	12.99	17.02	
	Average kidney fat (kg)			average
low	.93	1.13	1.38	1.15 ^A
medium	1.52	1.17	1.08	1.26 ^A
high	1.65	1.17	1.32	1.38 ^A
average	1.37 ^A	1.16 ^A	1.26 ^A	1.26
	Average separable fat (%) of the 10th rib section			average
low	17.3	19.9	17.7	18.3 ^A
medium	20.2	17.3	17.0	18.2 ^A
high	19.7	19.1	16.0	18.3 ^A
average	19.1 ^A	18.8 ^A	16.9 ^A	18.3
	Average rib-eye area (inches)			average
low	6.58	7.50	7.08	7.06 ^A
medium	6.83	7.17	8.17	7.39 ^A
high	6.17	8.00	8.92	7.69 ^A
average	6.53	7.56 ^{ab}	8.06 ^b	7.38
	Average separable lean (%) of the 10th rib section			average
low	65.9	63.7	64.0	64.5 ^A
medium	63.2	62.5	67.4	64.0 ^A
high	62.8	65.8	66.4	65.0 ^A
average	63.9 ^A	64.0 ^A	66.0 ^A	64.6

^A means in the same group which are followed by a common superscript are not significantly different ($P < 0.05$).

^{a b} means in the same group which are followed by a common superscript are not significantly different ($P < 0.01$).

cent retail cuts of beef carcasses. These authors found that the weight of kidney fat plus heart fat was highly significantly correlated ($-.69$) to the percent primal retail cuts of the carcasses studied. The significance of this correlation was thought to be a result of the good estimate of carcass fat provided by the weight of kidney fat plus heart fat. Moody et al. (1970) showed that the weight of the kidney knob was highly significantly correlated with the percent carcass fat ($+.48$) and the total carcass fat ($+.51$).

It would appear, then, that the weight of kidney fat provides a good indication of the percent of separable fat in the carcass. Based on the weight of kidney fat of the animals used in this experiment, increasing the energy consumption increased fat deposition. This trend was more pronounced in animals receiving low protein diets than animals on the medium and high protein rations. Animals receiving low protein diets had a higher percent carcass fat than those on high protein diets. This trend was evident only in animals on the medium and high energy diets. These results are similar to those reported by other authors. In studies on the effect of protein level on carcass composition in beef cattle, Robertson et al. (1970) reported an increase in the carcass kidney fat in animals receiving an 11-percent crude protein ration compared to those receiving rations containing 14 and 20 percent crude protein. Waldman et al. (1971) found that animals above 227 kg weight deposited fat at a greater rate than muscle when fed high energy levels however fat and muscle were deposited at similar rates in animals fed medium levels of energy. Norton et al. (1970) fed diets containing 12.0, 28.5 and 45.5 percent crude protein to lambs. They found that as the protein content of the diet increased, the fat content of the gain decreased. Studies on the effect of dietary protein and feeding level on the body

composition of lambs (Andrews and Orskov, 1970b) revealed an increase in the deposition of body fat with increasing feeding level. There was also a decrease in the rate of fat deposition with increases in dietary crude protein; the effect being particularly marked at the high level of feeding. These trends in the fat content of carcass due to the effects of different protein and energy intakes are similar to those observed in this experiment when kidney fat was used as an indicator of carcass fat content.

Rib separation data has been shown to be of value in judging carcass merit. Hankins and Howe (1946) used separable fat, lean and bone of the 9-10-11 rib section to develop equations for predicting separable carcass muscle. Busch et al. (1968) evaluated the use of separable fat, lean and bone of the 9-10-11 rib section as a method of predicting the edible portion of beef carcasses. These authors found that the separable fat of the 9-10-11 rib section was highly negatively correlated with percent carcass lean. They concluded that the percent separable fat of the 9-10-11 rib cut is equivalent to estimated total carcass fat in predicting the edible portion of beef carcasses. Crown and Damon (1960) found that the separable components of the 12th rib section were equally as effective in estimating carcass quality as the separable components of the 9-10-11 rib section. The calculated correlation coefficients between separable fat of the single rib section and separable fat of the 9-10-11 rib section was highly significant at 0.965. The correlation coefficient between separable fat of the single rib section and total separable fat of the carcass was also highly significant at +0.962. Percent separable fat of a single rib section appears to be a fair indicator of the percent separable fat of the total carcass.

In this experiment, animals receiving low, medium and high protein rations had an average of 19.1, 18.8 and 16.9 percent separable fat res-

pectively, in the 10th rib section (Table 7). In the low protein group, animals receiving medium and high energy levels had a higher percent separable fat content in the 10th rib section than those on the low energy diet. In the medium and high protein groups, however, there was no increase in the fat content of the 10th rib section with increasing energy intake (Table 7). This trend is in agreement with that observed for weight of kidney fat. Differences in the percent separable fat content of the 10th rib section due to changes in the energy or protein intake were not statistically significant ($P < 0.05$). The 10th rib section from bulls contained an average of 17.7 percent separable fat compared to 19.5 percent in that from steers. These values were not significantly different ($P < 0.05$).

Epley et al. (1970) presented evidence indicating that the thickness of fat over the longissimus dorsi muscle between the 11th and 12th ribs was highly significantly correlated with the percent trimmed retail cuts (+0.71). There was a close relationship between subcutaneous fat thickness over the longissimus dorsi muscle and the percent separable fat of beef carcasses (Moody et al., 1970).

The thickness of the fat layer over the longissimus dorsi muscle was measured between the 11th and 12th ribs. Three measurements were taken by a Canada Department of Agriculture government grader according to Canadian standards. The average of these three measurements was used to represent the fat thickness over the longissimus dorsi muscle between the 11th and 12th ribs.

There was an increase in the thickness of the fat cover over the longissimus dorsi muscle with increasing energy intake. Animals consuming low, medium and high levels of energy had averages of 0.05, 0.08 and 0.10 inches of fat cover, respectively. Animals on the low, medium

and high protein rations had averages of 0.06, 0.09 and 0.08 inches of fat over the longissimus dorsi muscle.

The average fat thickness was sufficiently thin in all cases (below 0.2 inches) that it is questionable if the precision of the measuring technique was adequate to detect quantitative differences. None of the differences in fat thickness over the longissimus dorsi muscle between different treatment groups were significant ($P < 0.05$).

The trends in carcass fat content as indicated by kidney fat weight, percent separable fat of the 10th rib section, and fat thickness over the longissimus dorsi muscle were very similar. From these three indices, it appears that there was an increase in the percent of separable carcass fat with increasing energy intake. This trend was more marked in animals receiving the low protein diet than in those receiving the medium and high protein levels. The animals on the low protein diets had a higher percent carcass fat than animals on the high protein diets. This trend was more evident in the animals on high and medium energy levels than in animals receiving low energy intake, as indicated by the weight of kidney fat and the percent separable fat of the 10th rib section.

Estimates of Separable Carcass Lean

The area of the longissimus dorsi muscle between the 11th and 12th rib and the percent separable lean in the 10th rib section were used to indicate differences in the amount of lean among carcasses from the different treatment groups.

The averages of the area of the longissimus dorsi muscle between the 11th and 12th rib (rib-eye area) for the 9 treatment groups are given in Table 7. There was an increase in rib-eye area with increasing pro-

tein intake. Animals receiving the low, medium and high protein diets had rib-eye areas averaging 6.53, 7.56 and 8.06 square inches, respectively. These values were significantly different ($P < 0.01$). The increase was more pronounced in animals receiving medium and high energy than in those fed the low energy diet. There was a slight increase in the rib-eye area with increasing energy intake. Average rib-eye areas of animals fed low, medium and high energy diets were 7.06, 7.39 and 7.69 square inches, respectively. This increase was largely due to the increase in rib-eye area of animals fed the high protein diets. The differences in rib-eye area due to different energy intakes were not significantly different ($P < 0.05$). The rib-eye area for bulls and steers averaged 8.10 and 5.94 square inches, respectively. Bulls had significantly larger rib-eye areas than steers ($P < 0.01$).

The rib-eye area is one of the most widely used and easily available measurements for estimating the content of carcass lean (Bray et al., 1969). Busch et al. (1968), Cole et al. (1960), Epley et al. (1970), Fitzhugh et al. (1965), Hedrick et al. (1965) and Moody et al. (1970) reported correlation coefficients between the rib-eye area and the weight of separable lean or edible portion of beef carcasses. Correlation coefficients ranging from $+^{\circ}.43$ to $+^{\circ}.70$ were obtained by these authors. All correlations were statistically significant ($P < 0.01$). However, correlations between rib-eye area and the percent of carcass lean were low and not significant. The major reason for the high correlation between longissimus dorsi area and the weight of carcass lean was their common correlation with carcass weight. Due to the wide range in slaughter weights of the animals in this experiment, the trends observed from average rib-eye areas were probably more indicative of variations in carcass weight than percentage of separable carcass lean.

The average percentages of separable lean in the 10th rib section for the 9 treatment groups are given in Table 7. There was an increase in the percent separable lean of the 10th rib section with increasing protein in the diet. Animals receiving low, medium and high protein diets had, on the average, 63.9, 64.0 and 66.0 percent separable lean, respectively. The increase was evident only in animals receiving medium and high energy. There was no increase in the percent separable lean with increasing protein in animals receiving low energy diets. Animals receiving low, medium and high energy diets had, on the average, 64.5, 64.4 and 65.0 percent separable lean in the 10th rib section. Differences in the average percent separable lean among the 9 treatment groups were not significantly different ($P < 0.05$). Bulls and steers had an average of 65.7 and 62.5 percent separable lean in the 10th rib section, respectively. Bulls had a significantly higher percent separable lean than steers ($P < 0.05$).

Crown and Damon (1960) presented data showing a highly significant correlation (+ .818) between separable lean of the 12th rib section and total carcass separable lean. Moody et al. (1970) found that the weight of the edible portion of the 9-10-11 rib section was highly significantly correlated to the weight of edible meat in the carcass (+.50) and to the percent of edible meat in the carcass (+.60). It would seem, then, that the percent separable lean of the 10th rib section provides a fair indication of the percent carcass lean.

The changes in carcass lean content which occurred with varying levels of dietary protein, as indicated in this experiment by percent separable lean of the 10th rib section, are in close agreement with the results of work done by Andrews and Orskov (1970b) and Norton et al. (1970). In studies with early weaned lambs, Andrews and Orskov (1970b) found an

increase in the rate of protein deposition with increasing dietary crude protein. This effect was particularly marked at the high level of feeding. Norton et al. (1970) found that the body protein content of lambs increased as dietary protein increased.

Chemical Analysis of Separable Fat and Lean

Separable fat from the 10th rib section was analyzed for nitrogen and dry matter content. There was a decrease in the nitrogen content of the separable fat with increasing energy intake. Animals receiving the low, medium and high levels of energy had 2.77, 2.61 and 2.10 percent nitrogen, respectively, in the separable fat of the 10th rib section (Table 8). On the average the animals receiving the high energy diets had a significantly lower ($P < 0.05$) percentage nitrogen in the separable fat of the 10th rib section than animals receiving medium or low energy diets. There was also a decrease in the nitrogen content of the separable fat with increasing protein level in the ration. Animals receiving low, medium and high protein diets had 2.61, 2.50 and 2.37 percent nitrogen, respectively in the separable fat of the 10th rib section. These values were not significantly different ($P < 0.05$).

There was an increase in the dry matter content of the fat with increasing energy consumption. This increase was evident at all three protein levels. Animals fed low, medium and high energy diets had averages of 66.8, 69.1 and 72.6 percent dry matter in the separable fat of the 10th rib section, respectively (Table 8). These values were significantly different ($P < 0.05$). There were no detectable significant differences ($P < 0.05$) in the dry matter content of the separable fat due to different dietary protein levels.

The separable lean of the 10th rib section was analyzed for ether

Table 8

Chemical analysis of separable fat and lean (%)

Energy level	Dietary crude protein level (%)			
	8.95	12.99	17.02	
<u>Nitrogen content of fat</u>				average
low	2.75	3.16	2.41	2.77 ^A
medium	3.05	2.27	2.51	2.61 ^A
high	2.03	2.07	2.20	2.10 ^B
average	2.61 ^A	2.50 ^A	2.37 ^A	
<u>Dry matter content of fat</u>				average
low	65.8	65.5	67.9	66.4 ^A
medium	66.6	71.9	68.6	69.1 ^{AB}
high	73.4	72.4	72.0	72.6 ^B
average	68.6 ^A	69.9 ^A	65.5 ^A	
<u>Ether extract content of lean</u>				average
low	16.7	15.6	17.0	16.4 ^A
medium	16.9	16.6	12.1	15.2 ^A
high	18.0	16.0	13.5	15.8 ^A
average	17.2 ^A	16.1 ^A	14.2 ^A	
<u>Nitrogen content of lean</u>				average
low	12.7	12.6	12.8	12.7 ^A
medium	12.5	12.9	13.3	12.9 ^A
high	12.3	12.9	13.3	12.8 ^A
average	12.5 ^A	12.8 ^A	13.2 ^A	

A B means in the same group which are followed by a common superscript are not significantly different ($P < 0.05$).

extract, nitrogen and dry matter content. There was a decrease in the ether extract of the separable lean with increasing protein in the diet. Animals receiving low, medium and high protein diets had averages of 17.2, 16.1 and 14.2 percent ether extract in the separable lean, respectively (Table 8). The decrease was evident only in animals on the medium and high energy diets. This trend is similar to that which occurred in carcass fat content as indicated by weight of kidney fat and percent separable fat of the 10th rib section. There was no decrease in ether extract of the separable lean with increasing dietary protein in animals on the low energy diet.

There was a slight increase in the percent nitrogen of the separable lean with increasing protein in the diet. This increase was evident only in animals receiving medium and high energy. Animals receiving low, medium and high protein diets had, on the average, 12.5, 12.8 and 13.2 percent nitrogen in the separable lean of the 10th rib section, respectively (Table 8). These values were not significantly different ($P < 0.05$). Changes in the nitrogen content of the lean with different dietary energy levels were not significantly different ($P < 0.05$). Dry matter content of the lean averaged 25.2 percent. There were only slight differences in dry matter content of the lean between different treatment groups. None of the differences were statistically significant ($P < 0.05$).

Summary and Conclusions

Conclusions drawn from this study must be confined to particular parameters. Animals of a different weight range or age, rations with different levels of roughage, or feeding levels restricted to near maintenance or below maintenance levels may result in different responses to changes in the dietary protein and energy levels. Different climatic conditions may alter the response to varying dietary protein and energy levels because of the differences in levels of activity and metabolic processes associated with climatic change. Breed differences may also alter the optimal ratio of protein and energy due to different inherent growth patterns.

The results in this study were obtained with Holstein bulls and steers with an average initial weight of 170 kg and an average slaughter weight of 292 kg. The weights of individual animals ranged between 93.5 and 390.5 kg liveweight (lowest to the highest weight over the feeding period). The rations were highly digestible, all-concentrate rations fed at above maintenance levels.

In this experiment, increasing the energy intake (from 318 to 358 and from 358 to 398 kcal GE/Wkg^{3/4}/day) increased the rate of gain regardless of the protein level being fed. The response to the highest energy level, however, was greater in animals receiving medium and high protein rations than in those receiving the low protein diets. It appears that with the ration containing 8.95 percent crude protein, low protein was a limiting factor at the high energy level. Under the conditions of this experiment, if low protein rations are fed (8.95 percent crude protein and supplying 8.26 g CP/Wkg^{3/4}/day) there is little increase in the rate of gain brought about by increasing the energy intake beyond the medium level (358 kcal GE/Wkg^{3/4}/day).

Increasing the protein intake (from 8.26 to 11.99 and from 11.99 to 15.71 g CP/Wkg^{3/4}/day) increased the rate of gain regardless of the energy level being fed. The response to the highest protein intake, however, was greater in animals receiving medium and high energy diets than in those receiving the low energy diet. It appears that with the energy level of 318 kcal GE/Wkg^{3/4}/day, low energy was a limiting factor at the high protein level. Under the conditions of this experiment, if low energy diets are fed (318 kcal GE/Wkg^{3/4}/day) there is little increase in rate of gain brought about by increasing the protein intake beyond the medium level (12.99 percent crude protein and supplying 11.99 g CP/Wkg^{3/4}/day).

It is evident that the energy level must be considered in setting protein requirements for ruminant diets. Although there was no significant increase in the rate of gain brought about by increasing the protein level to 17.2 percent dietary crude protein, a significant increase might have been obtained with this high protein level and the high energy diets, if more animals had been fed these diets. If rations having a higher concentration of energy than those used in this experiment were fed ad libitum, there might be an advantage to increasing the dietary crude protein to levels above the medium level used in this experiment in order to achieve higher daily gains.

The efficiency of utilization of the ration dry matter, gross energy and crude protein for weight gain was highest at the high energy levels. Increasing the protein level of the ration from 8.95 to 12.99 percent was effective in increasing the efficiency of utilization of dry matter and gross energy for weight gain. Increasing the protein level to 17.02 percent crude protein did not result in a further increase in the efficiency of dry matter and gross energy utilization.

From indices used to indicate carcass fatness, it appeared that there was an increase in the percent separable carcass fat with increasing energy intake. This observation is complemented by the increase in energy retention noted with increasing energy intake. This increase was more marked in animals fed the low protein diet than in those receiving the medium and high protein diets. Animals on the low protein diet had a higher percent separable carcass fat than animals on the high protein diet. This trend was more evident in animals fed high and medium energy levels than in animals on the low energy diet.

Indices used to evaluate carcass leanness indicated that the percent of carcass lean followed trends opposite to those indicated for percent of carcass fat, as would be expected. There was an increase in the percent carcass lean with increasing dietary crude protein intake. This observation is complemented by the increase in nitrogen retention noted with increasing protein intake. This increase was evident only in animals fed at the medium and high energy levels.

There was a decrease in the percent ether extract and an increase in the percent nitrogen in the separable lean of the 10th rib section with increasing dietary protein intake. This may result from less intramuscular fat being deposited in animals being fed the high protein rations.

The tendency for increased energy intake to result in an increase in the proportion of carcass fat was more marked at the low protein level. The tendency for increased protein intake to result in an increase in the proportion of carcass lean was more marked at the medium and high energy levels. Animals receiving the low protein diet seem to have channelled extra energy into fat storage while animals on the high protein diets appear to have utilized additional energy

for production of lean meat.

Again it is evident that dietary protein levels for ruminants cannot be set without consideration of the energy intake. Increasing the energy intake without increasing the protein level results in increased carcass fat content. Increasing the protein intake without increasing energy intake inhibits the maximization of carcass lean deposition. Factors affecting carcass composition will become more important considerations in setting dietary protein levels as the estimation of carcass composition becomes a more widespread practice in the meat industry.

Bulls had a 43 percent higher daily gain and required 5 percent less dry matter per kg gain than the steers in this experiment. The carcasses from bulls had a lower percent separable fat and a higher percent separable lean than steer carcasses. The different growth patterns for bulls compared to steers did not appear to result in different responses to the protein and energy levels used in this study.

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Appendix

Mean squares obtained by analysis of variance

Variable	Source of Variation	Degrees of freedom	Mean squares	
Average daily gain	Sex	2	448750.0	**
	Energy	2	530520.0	**
	Sex X Energy	4	24483.0	
	Protein	2	395630.0	**
	Sex X Protein	4	13571.0	
	Energy X Protein	4	6049.5	
	Error	8	9733.0	
	Total	26		
Dry matter/kg gain	Sex	2	0.164	
	Energy	2	1.043	*
	Sex X Energy	4	0.074	
	Protein	2	3.111	**
	Sex X Protein	4	0.151	
	Energy X Protein	4	0.038	
	Error	8	0.186	
	Total	26		
Gross energy/kg gain	Sex	2	3.103	
	Energy	2	17.770	*
	Sex X Energy	4	1.107	
	Protein	2	62.848	**
	Sex X Protein	4	2.808	
	Energy X Protein	4	0.684	
	Error	8	3.505	
	Total	26		
Crude protein/kg/gain	Sex	2	3506.7	
	Energy	2	19968.0	*
	Sex X Energy	4	1890.4	
	Protein	2	124580.0	**
	Sex X Protein	4	2563.5	
	Energy X Protein	4	896.2	
	Error	8	4293.7	
	Total	26		

Variable	Source of Variation	Degrees of freedom	Mean squares
Apparent digestible dry matter (%)	Sex	2	54.068*
	Energy	2	1.305
	Sex X Energy	4	0.666
	Protein	2	51.229
	Sex X Protein	4	2.126
	Energy X Protein	4	4.626
	Error	8	12.001
	Total	26	
Apparent digestible gross energy (%)	Sex	2	42.785
	Energy	2	3.767
	Sex X Energy	4	5.259
	Protein	2	43.708
	Sex X Protein	4	5.392
	Energy X Protein	4	4.084
	Error	8	11.352
	Total	26	
Apparent digestible crude protein (%)	Sex	2	4665.1
	Energy	2	2620.6
	Sex X Energy	4	183.7
	Protein	2	71505.0**
	Sex X Protein	4	1279.0
	Energy X Protein	4	1881.6
	Error	8	2072.4
	Total	26	
Nitrogen intake (grams/day)	Sex	2	2.160
	Energy	2	19.888**
	Sex X Energy	4	0.192
	Protein	2	87.920**
	Sex X Protein	4	1.129
	Energy X Protein	4	1.392
	Error	8	0.380
	Total	26	

Variable	Source of Variation	Degrees of freedom	Mean squares	
Fecal nitrogen (grams/day)	Sex	2	9905.1	**
	Energy	2	8433.4	**
	Sex X Energy	4	711.3	
	Protein	2	2010.5	
	Sex X Protein	4	283.8	
	Energy X Protein	4	693.3	
	Error	8	488.0	
	Total	26		
Urinary nitrogen (grams/day)	Sex	2	228.22	
	Energy	2	25.96	
	Sex X Energy	4	131.51	
	Protein	2	706.43	
	Sex X Protein	4	114.02	
	Energy X Protein	4	39.46	
	Error	8	229.84	
	Total	26		
Nitrogen retention (grams/day)	Sex	2	658.4	
	Energy	2	2737.7	
	Sex X Energy	4	348.1	
	Protein	2	10436.0	**
	Sex X Protein	4	858.0	
	Energy X Protein	4	141.3	
	Error	8	850.5	
	Total	26		
Nitrogen retained (as % of apparent digest- ible nitrogen)	Sex	2	441.97	
	Energy	2	428.23	
	Sex X Energy	4	306.36	
	Protein	2	113.26	
	Sex X Protein	4	164.12	
	Energy X Protein	4	73.99	
	Error	8	445.59	
	Total	26		

Variable	Source of Variation	Degrees of freedom	Mean squares	
Initial weight	Sex	2	21387.0	**
	Energy	2	1179.1	
	Sex X Energy	4	123.6	
	Protein	2	588.4	
	Sex X Protein	4	139.8	
	Energy X Protein	4	266.4	
	Error	8	505.5	
	Total	26		
Slaughter weight	Sex	2	32000.0	**
	Energy	2	5178.9	*
	Sex X Energy	4	294.1	
	Protein	2	4096.6	*
	Sex X Protein	4	246.4	
	Energy X Protein	4	651.9	
	Error	8	700.1	
	Total	26		
Weight gain	Sex	2	1334.7	**
	Energy	2	1444.5	**
	Sex X Energy	4	64.0	
	Protein	2	1625.5	**
	Sex X Protein	4	20.9	
	Energy X Protein	4	87.7	
	Error	8	151.8	
	Total	26		
Dressing percentage	Sex	2	0.739	
	Energy	2	3.628	
	Sex X Energy	4	1.584	
	Protein	2	5.463	*
	Sex X Protein	4	1.286	
	Energy X Protein	4	1.632	
	Error	8	1.101	
	Total	26		

Variable	Source of Variation	Degrees of freedom	Mean squares
Kidney fat (kg)	Sex	2	0.177
	Energy	2	0.117
	Sex X Energy	4	0.107
	Protein	2	0.100
	Sex X Protein	4	0.123
	Energy X Protein	4	0.197
	Error	8	0.245
	Total	26	
Separable fat of the 10th rib section (%)	Sex	2	11.108
	Energy	2	0.074
	Sex X Energy	4	8.484
	Protein	2	12.468
	Sex X Protein	4	7.896
	Energy X Protein	4	7.030
	Error	8	4.585
	Total	26	
Rib-eye area	Sex	2	17.419 ^{**}
	Energy	2	0.919
	Sex X Energy	4	0.488
	Protein	2	5.461 ^{**}
	Sex X Protein	4	0.082
	Energy X Protein	4	1.249
	Error	8	0.506
	Total	26	
Separable lean of the 10th rib section (%)	Sex	2	38.938 [*]
	Energy	2	0.908
	Sex X Energy	4	5.047
	Protein	2	11.613
	Sex X Protein	4	11.011
	Energy X Protein	4	12.368
	Error	8	5.253
	Total	26	

Variable	Source of Variation	Degrees of freedom	Mean squares
Nitrogen content of separable fat (%)	Sex	2	0.227
	Energy	2	1.111*
	Sex X Energy	4	0.628
	Protein	2	0.127
	Sex X Protein	4	0.592
	Energy X Protein	4	0.397
	Error	8	0.196
	Total	26	
Dry matter content of separable fat (%)	Sex	2	9.667
	Energy	2	87.083*
	Sex X Energy	4	32.534
	Protein	2	4.016
	Sex X Protein	4	5.426
	Energy X Protein	4	11.957
	Error	8	16.971
	Total	26	
Ether extract content of separable lean (%)	Sex	2	3767.9 *
	Energy	2	339.2
	Sex X Energy	4	1868.5
	Protein	2	2063.7
	Sex X Protein	4	1116.1
	Energy X Protein	4	929.1
	Error	8	569.4
	Total	26	
Protein content of separable lean	Sex	2	81.708
	Energy	2	8.138
	Sex X Energy	4	43.94
	Protein	2	95.77
	Sex X Protein	4	43.39
	Energy X Protein	4	20.08
	Error	8	41.96
	Total	26	

Variation	Source of Variation	Degrees of freedom	Mean squares
Dry matter content of separable lean	Sex	2	5.208 ^{**}
	Energy	2	0.223
	Sex X Energy	4	0.623
	Protein	2	0.370
	Sex X Protein	4	0.126
	Energy X Protein	4	0.107
	Error	8	0.169
	Total	26	

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